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Fracture resistance of roots following instrumentation with two single-file and one multi-file nickel–titanium rotary systems

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Abstract

Objective: This study aimed to compare the fracture resistance of human mandibular premolar roots after instrumentation with different nickel–titanium (NiTi) rotary systems.

Methods: Forty extracted human mandibular premolars were decoronated and randomly assigned to four groups (n=10). Group 1 served as an uninstrumented control, while Groups 2–4 were prepared using different NiTi rotary systems according to the manufacturers' protocols: One Curve (OC) single-file system (Group 2), XP-Endo Shaper (XPS) single-file system (Group 3), and ProTaper NEXT (PTN) multi-file system (Group 4). All instrumented canals were obturated with gutta-percha and AH Plus sealer using the lateral compaction technique. Vertical fracture resistance was then tested with a universal testing machine. Data were analyzed using one-way ANOVA followed by Tukey's post hoc test (α=0.05).

Results: ANOVA revealed a significant difference in fracture resistance among the groups (P=0.005). The control group (402 ± 115.93 N) showed significantly higher mean fracture resistance compared to all instrumented groups (P < 0.05). Among the instrumented groups, XPS (304 ± 37.47 N) had the highest mean fracture resistance, followed by OC (291 ± 78.37 N) and PTN (288 ± 50.50 N), but these differences were not statistically significant (P > 0.05).

Conclusions: Root canal instrumentation with both single-file and multi-file NiTi rotary systems significantly reduced fracture resistance compared to uninstrumented roots. There was no significant difference in fracture resistance between the single-file and multi-file systems, indicating that the single-file approach does not provide an advantage in preserving root strength.

Keywords: Endodontically treated teeth, Fracture resistance, Ni-Ti, Root canal filing, Root canal preparation, Root canal therapy

Introduction

The preservation of teeth is a key goal in maintaining long-term oral health. Endodontic treatment plays a crucial role in achieving this goal through retaining structurally compromised teeth, whether fractured, carious, or traumatised, for extended periods (1). Root canal therapy involves a sequence of procedures, including removal of pulpal tissue, chemo-mechanical cleaning and shaping of the root canals, followed by obturation of the canal space (2). Among these steps, root canal instrumentation is a critical phase because it eliminates the bacterial load, thereby promoting biological healing and also enabling effective obturation (3).

Over the years, various endodontic file systems have been developed, evolving in design, metallurgy, and clinical protocols. Nickel–titanium (NiTi) alloy, introduced by Buehler in 1963, was an important development in root canal instruments due to its unique properties of shape memory and superelasticity. Compared with stainless steel, NiTi exhibits higher strength and a lower modulus of elasticity, enabling safer and more efficient canal shaping (4). Since the 1990s, NiTi rotary instruments have undergone significant advancements in manufacturing techniques, resulting in a wide array of file systems with varying designs, tapers, and file sequences (5).

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Root canal instrumentation inevitably affects the remaining dentin thickness, which is a key factor in determining the root's resistance to fracture. Excessive dentin removal during canal shaping weakens the root structure and increases the risk of vertical root fracture (VRF). VRF is one of the most serious complications of endodontic treatment, often leading to tooth extraction(6-8). Preserving sufficient radicular dentin is therefore essential for long-term tooth survival (9). It is believed that crack initiation is strongly associated with canal instrumentation, while filling techniques may contribute mainly to the propagation of cracks (10).

Endodontically treated teeth are more susceptible to fracture than vital teeth due to the cumulative loss of tooth structure from caries, access cavity preparation, and canal instrumentation (11, 12). Previous studies indicated that root canal preparation substantially decreases fracture resistance, with rotary NiTi instruments producing more dentinal cracks compared to hand filing (13-15). Crack initiation and propagation are influenced by several factors, including instrument stiffness, taper, cross-sectional design, and alloy type, all of which may contribute to the eventual development of VRFs (16, 17).

In recent years, the concept of minimally invasive endodontics, often expressed as 'less is more,' has gained increasing acceptance. This approach favors the use of single-file systems that complete canal shaping with a single instrument, thereby reducing treatment time, minimizing canal enlargement, and preserving radicular dentin (18). Modern NiTi systems, especially single-file designs, aim to balance effective cleaning with conservative dentin removal (19).

One Curve (OC; Micro-Mega, Besançon, France) is a single-file system, introduced in 2018. It is fabricated from heat-treated C-Wire alloy, which is a type of nickel-titanium (NiTi) alloy that undergoes a proprietary heat treatment process to grant it controlled memory properties. It has a constant 25/.06 taper and a variable cross-section, which allows it to adapt efficiently to canal curvatures while reducing dentinal stress (20).

The XP-Endo Shaper (XPS; FKG Dentaire SA, Chaux-de-Fonds, Switzerland), introduced in 2015, is made from MaxWire alloy, which is a NiTi alloy specifically developed by FKG Dentaire. This alloy exhibits special properties of shape memory and superelasticity. The XPS undergoes a shape transformation, changing its taper from an initial 30/.01 to approximately 30/.04 at body temperature. This adaptive design provides high flexibility, allowing the instrument to closely conform to the canal anatomy and conservatively preserve the dentin structure during shaping (21).

ProTaper NEXT (PTN; Dentsply Maillefer, Ballaigues, Switzerland) is a multiple-file system. It is made from M-Wire alloy, which is a nickel-titanium (NiTi) alloy that undergoes a proprietary thermal treatment by Dentsply Maillefer. PTN features an off-centre rectangular cross-section. This design produces a swaggering rotational motion that improves debris removal. However, the sequential use of multiple instruments with varying tapers may lead to increased dentin removal and higher stress on the canal walls (22).

Several studies have evaluated the impact of various NiTi systems on root fracture resistance. However, little information is available concerning the comparisons of OC, XPS, and PTN under standardized in vitro conditions. Such comparisons are essential to determine whether newer single-file systems offer an advantage in preserving root integrity over conventional multi-file systems. Therefore, the present study aimed to evaluate the fracture resistance of roots instrumented with two single-file systems (OC and XPS) and one multi-file system (PTN), as compared to uninstrumented roots.

Materials and Methods

The study protocol was approved by Vishnu Dental College's Institutional Ethical Committee with the reference number (IECVDC/19/PG01/CE/IVT/46).

Sample Preparation

The sample size was determined using G*Power (version 3.1.9.2; Heinrich Heine University, Düsseldorf, Germany). Based on an effect size (f = 0.55) derived from pilot data, with a 5% significance level and 80% power, the minimum required sample size was 10 specimens per group. Accordingly, 40 samples were included in the present study.

Forty freshly extracted human mandibular premolars with single roots, intact crowns, and fully formed apices were selected. The exclusion criteria involved teeth exhibiting caries, anatomical anomalies, cracks, craze lines, or microfracture. These conditions were assessed under a dental operating microscope (LABOMED, Los Angeles, CA, USA) at 17× magnification. All teeth were ultrasonically cleaned and stored in normal saline.

At the time of the experiment, the crowns were sectioned with a diamond disc (KG Sorensen, Brazil) under water cooling to standardize root length at 13 mm (23).

Tooth Standardization

The buccolingual (BL) and mesiodistal (MD) root dimensions were measured at the decoronation level using a digital caliper (Mitutoyo, Kawasaki, Japan), and the product of these values was calculated to assess cross-sectional size. Sample weights were also recorded using a precision balance (CY513; ACZET Ltd., Mumbai, India). One-way ANOVA confirmed homogeneity among groups, with no statistically significant differences in weight ($P = 0.887$) or dimensional product ($P = 0.997$). Based on these parameters (24), specimens were randomly allocated into three experimental groups and one control group. Canal patency was verified with a #15 K-file (Mani Inc., Tochigi, Japan). The working length (WL) was determined by subtracting 0.5 mm from the length at which the file tip first appeared at the apical foramen (25).

Study Groups and Instrumentation Process

Root canal instrumentation was performed with an endodontic motor (E-Connect S; Eighteeth, Changzhou, Jiangsu, China), using the torque and speed settings recommended by each manufacturer. A new instrument was used for each canal and then discarded. All procedures were performed by a single calibrated operator to ensure consistency.

The study groups were assigned as follows:

Group I (Control, uninstrumented): No instrumentation was performed in the control group.

Group II (OC, single-file system): In this group, instrumentation was carried out using the One Curve (25/.06) single-file system (Micro-Mega, Besançon, France) in continuous rotation at 300 rpm and 2.5 N·cm torque until the working length was reached (Figure 1A). A brushing motion was applied along the canal walls during instrumentation. After every three strokes, the file was withdrawn and cleaned with sterile gauze.

Group III (XPS, single-file system): The specimens in this group were instrumented with the XP-Endo Shaper (30/.01 expanding to 30/.04) single-file system (FKG Dentaire SA, Chaux-de-Fonds, Switzerland). The file was operated at 800 rpm with a torque of 1 N·cm (Figure 1B). The file was advanced with light apical pressure using an in-and-out pecking motion of approximately 3 mm, combined with a gentle brushing motion against the canal walls, until the working length was reached.

Group IV (PTN, multi-file system): In this group, instrumentation was conducted with the ProTaper NEXT multi-file system (X1: 17/.04, X2: 25/.06; Dentsply Sirona, Ballaigues, Switzerland) at 300 rpm and 4 N·cm torque (Figure 2). The X1 file (Figure 2A) was introduced passively to the working length, then withdrawn 2–3 mm, and applied with an outward brushing motion to enlarge the coronal and middle thirds. It was then reintroduced to the working length with gentle brushing in the apical third. This “touch-and-brush” sequence was repeated 2–3 times, after which the X2 file (Figure 2B) was used in the same manner.

All canals were prepared to the established working length, confirmed with a #15 hand K-file.

Irrigation Protocol

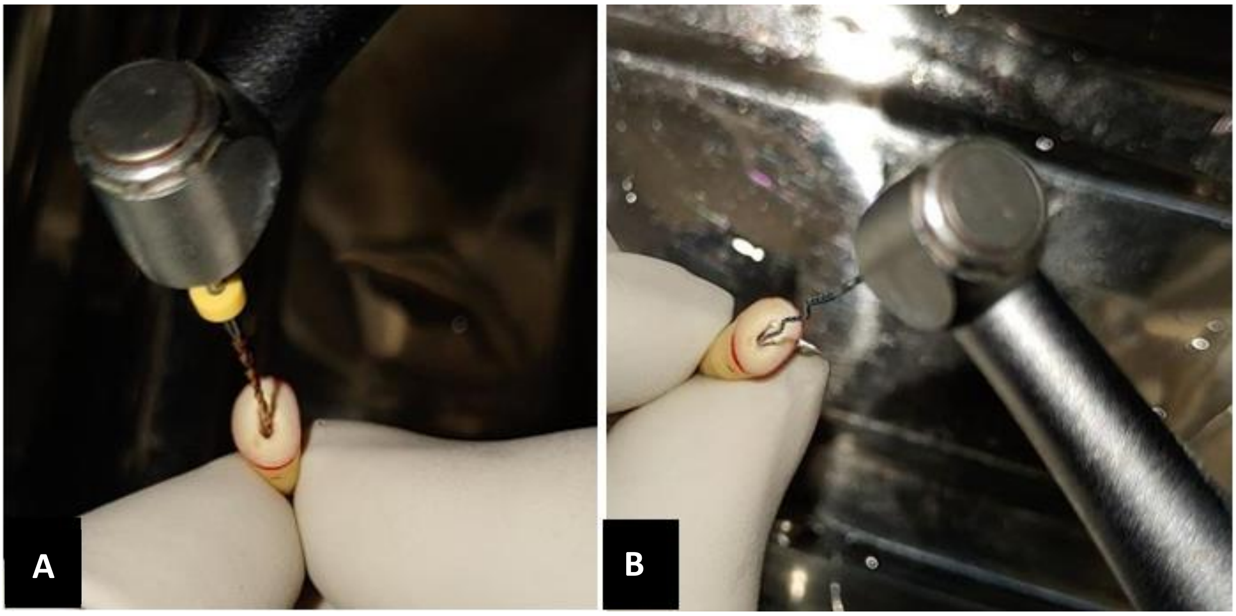

Figure 1. A) Instrumentation with One Curve. B) Instrumentation with XP-Endo Shaper.

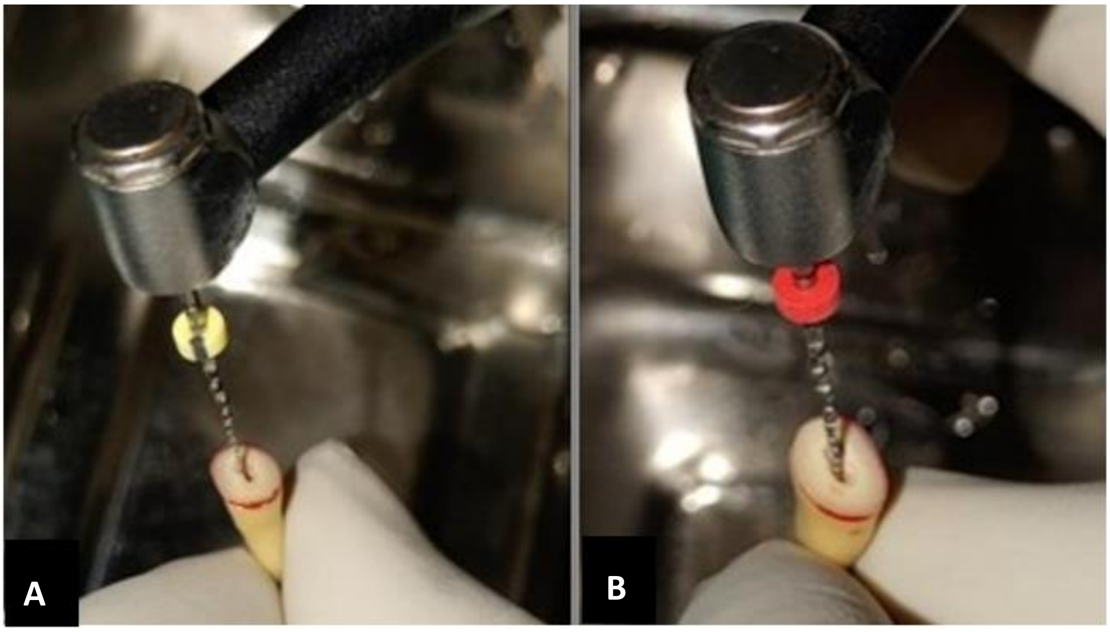

Figure 2. A and B Instrumentation with ProTaper NEXT X1 file (A) and ProTaper NEXT X2 file (B)

During instrumentation, irrigation was performed using 2 mL of 2.5% sodium hypochlorite (Prime Dental Products, Mumbai, India), applied with a 27-gauge needle after each instrument cycle. Final irrigation was carried out with 5 mL of 17% EDTA, followed by 5 mL of 2.5% sodium hypochlorite, and finally 5 mL of distilled water. Canals were then dried using absorbent paper points (Prime Dental Products).

Obturation Procedure

Specimens in the experimental groups (OC, XPS, PTN) were obturated using corresponding gutta-percha master cones (Prime Dental Products) with AH Plus sealer (Dentsply DeTrey, Konstanz, Germany). The sealer was placed into the canal using a lentulo spiral (Mani Inc.), followed by lateral compaction with a size 25 finger spreader (Mani Inc.) and accessory cones. Excess gutta-percha was removed with a heated hand plugger (GDC, Hoshiarpur, India). The coronal 1 mm of the filling was removed, and the orifices were sealed with a temporary restorative material (TMP RS, Prime Dental Products). Samples were stored at 37°C and 100% humidity for 7 days (26).

Periodontal Ligament Simulation and Mounting

To simulate the periodontal ligament, each root was wrapped in a single layer of aluminum foil (Minaxi Polypack, Gujarat, India) and then embedded vertically in self-curing acrylic resin (DPI, India) within a cylindrical mold, leaving 2 mm of the coronal root exposed. After the resin set, the teeth were removed, and the foil was peeled away. Then, a light-body silicone impression material (Reprosil, Dentsply, Switzerland) was injected into the socket. The teeth were repositioned, and excess silicone was trimmed to ensure a proper fit.

Fracture Testing

Each specimen was placed on the lower plate of a universal testing machine (Instron 3369; Norwood, MA, USA). A stainless-steel conical tip was aligned over the canal orifice, and a vertical compressive load was applied at a crosshead speed of 1 mm/min until fracture occurred (Figure 3). The maximum load required to fracture each root was recorded in Newtons (N).

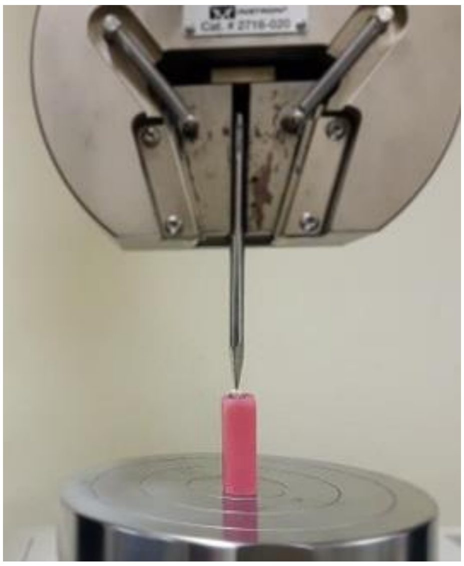

Figure 3. A sample mounted in the testing machine for evaluation of fracture load.

Statistical Analysis

Data analysis was performed using IBM SPSS Statistics for Windows, Version 21.0 (IBM Corp., Armonk, NY, USA). Data normality was assessed with the Kolmogorov–Smirnov test. Intergroup comparisons were made using one-way analysis of variance (ANOVA) with Tukey's post hoc test. A significance level of $P < 0.05$ was considered statistically significant.

Results

Table 1 presents the mean fracture load values (in Newtons) and standard deviations (SD) for the study groups. ANOVA revealed a significant difference in fracture resistance among the groups ($P = 0.005$). The control group (Group I, uninstrumented) demonstrated the highest mean fracture resistance (402 ± 115.93 N), which was significantly greater than all instrumented groups ($P<0.05$; Table 1).

Among the instrumented groups, Group III (XP-Endo Shaper) showed the highest mean fracture resistance (304 ± 37.47 N), followed by Group II (One Curve; 291 ± 78.37 N) and Group IV (ProTaper NEXT; 288 ± 50.50 N). However, the differences in fracture resistance were not statistically significant among the experimental groups ($P > 0.05$; Table 1).

Discussion

The present study investigated the fracture resistance of roots instrumented with two single-file NiTi rotary systems (One Curve and XP-Endo Shaper) and one multiple-file system (ProTaper NEXT), compared with an uninstrumented control group under standardized in vitro conditions. The results showed that roots prepared with One Curve (OC), XP-Endo Shaper (XPS), and ProTaper NEXT (PTN) demonstrated significantly lower fracture resistance than the uninstrumented control group, corresponding to an approximate reduction of 27.6%, 24.4%, and 28.4%, respectively. Similarly, Wu et al. (27) reported approximately a 30% reduction in vertical root fracture resistance of mandibular premolars following canal cleaning and shaping.

The reduction in fracture resistance during endodontic treatment is likely multifactorial (28). The removal of dentin during canal preparation makes the root walls thin, reducing the tooth's ability to withstand occlusal and lateral forces. Mechanical instrumentation and prolonged exposure to sodium hypochlorite alter collagen cross-linking, and in this way may compromise dentin's resilience and flexibility. Loss of moisture content further contributes to this effect, as dehydrated dentin becomes more brittle and susceptible to crack initiation. Irrigants, particularly at high concentrations, can also degrade both the collagen matrix and the mineral phase of dentin, thus weakening its structural integrity. In addition, mechanical stresses generated during instrumentation, especially in systems with greater taper or stiffness, can induce microscopic defects, while the compaction forces during obturation can propagate these flaws. Over time, such microcracks may merge under functional loading, ultimately increasing the risk of vertical root fracture.

Although the differences among the instrumented groups were not statistically significant, the XPS group demonstrated numerically higher fracture resistance than both the OC and PTN groups. This finding may be attributed to the unique design and metallurgical properties of the XPS. XPS is made from MaxWire alloy, a thermomechanically treated and electropolished NiTi alloy with phase transformation capability, which provides high flexibility. This flexibility allows the file to contract and expand within the canal, enabling better adaptation to complex anatomies and access to areas that conventional files may not reach (29). Unlike OC and PTN X2 files, which have a fixed taper of 0.06, the XPS begins with an ISO size 30 tip and a minimal 0.01 taper that dynamically expands to about 0.04 during use (30). The smaller effective taper makes XPS less aggressive and preserves more dentin, thereby reducing stress on canal walls and potentially explaining the

Table 1. Mean and standard deviation (SD) of fracture resistance (N) in the study groups

Group	File System	Brand	Mean ± SD (N)
I	Control (Uninstrumented)	-	402 ± 115.93[a]
II	single-file system	One Curve (OC)	291 ± 78.37[b]
III	single-file system	XP-Endo Shaper (XPS)	304 ± 37.47[b]
IV	multi-file system	ProTaper NEXT (PTN)	288 ± 50.50[b]
P-value	0.005*		

Different superscript letters indicate a significant difference as a result of Tukey's post hoc test ($P < 0.05$).
An asterisk (*) indicates a significant difference as a result of One-way ANOVA.

higher fracture resistance observed. Previous studies also reported the absence of new microcrack formation after instrumentation with XPS, highlighting its dentin-conserving characteristics (29, 31).

The OC instruments are made from C-Wire alloy that undergoes heat treatment to provide controlled memory. This property allows the files to be pre-bent, which facilitates navigation in curved canals. Their variable cross-section is designed to enhance centering and cutting efficiency (32). However, despite these design features, a previous study reported a higher incidence of crack formation with OC (26.7%) compared to HyFlex EDM (13.3%) (33). This may be related to its relatively low operating speed of 300 rpm, which reduces cutting efficiency and increases the contact time between the file and dentin, thereby concentrating stress.

PTN rotary files, made from M-Wire alloy, have an off-centered rectangular cross-section that produces a unique swaggering motion during rotation. This design, combined with its varying tapers, improves contact with canal walls and facilitates debris removal (26). However, extensive instrumentation can thin the root structure (34). Multi-file NiTi systems, which require sequential instrumentation, are linked to more dentin defects due to longer operating time, increased contact with canal walls, and higher stress concentrations that favor microcrack formation (35, 36). However, the present study found no significant difference in fracture resistance between the multi-file and single-file systems tested.

In contrast to the findings of this study, Katkam et al. (22) reported significantly fewer dentinal cracks with the single-file One Curve system compared to the multi-file ProTaper NEXT, particularly when minimal torque settings were used. Vadera et al. (37) used CBCT to compare dentin preservation among different NiTi systems. Their results showed that One Curve preserved dentin thickness more effectively than the TruNatomy and 2Shape multi-file systems, which may help reduce the risk of dentinal cracks and vertical root fractures. Nasiri and Wrbas (38). emphasized that heat-treated single-file systems such as XP-Endo Shaper and HyFlex EDM generated significantly fewer microcracks than traditional multi-file systems like ProTaper Gold and Reciproc Blue, especially in curved canals.

Although no statistically significant differences were found in fracture resistance among single- and multiple-file systems, the numerically higher fracture resistance observed with XPS may have clinical implications. In narrow or curved canals, single-file systems with reduced taper and greater flexibility, such as XP-Endo Shaper, may help preserve radicular dentin and reduce stress on canal walls, thereby supporting long-term tooth survival. Clinicians should create a balance between effective canal cleaning and dentin preservation to minimize the risk of vertical root fractures and improve the prognosis of endodontically treated teeth.

This study was performed under controlled in vitro conditions, which cannot fully reproduce the complexity of the oral environment. Factors such as cyclic masticatory forces, thermal changes, and fatigue loading were not simulated. In addition, the use of a static, unidirectional vertical load during fracture testing does not accurately reflect the dynamic and multidirectional forces that occur in vivo. Future studies should employ micro-CT to detect and monitor dentinal defects before and after instrumentation to better assess the formation and progression of microcracks across different file systems.

Conclusions

Within the limitations of this in vitro study, root canal instrumentation with both single-file systems (One Curve [OC] and XP-Endo Shaper [XPS]) and the multi-file system (ProTaper NEXT [PTN]) caused a significant reduction in fracture resistance compared with uninstrumented controls. Although no statistically significant differences were observed among the instrumented groups, the XPS group showed slightly higher fracture resistance, which may hold clinical relevance in cases with narrow or curved canals where dentin preservation is critical.

Acknowledgments

Not applicable.

Conflict of interest

The authors declare that they have no competing interests.

Author contributions

S.D.J. conceptualized the study and designed the research protocol. M.V.K. was responsible for data acquisition, performed the statistical analysis, supervised the work, and reviewed the manuscript. G.S. and J.B.M. interpreted the results and drafted the manuscript. K.S.R. contributed to the study design and conducted the literature review. S.M. assisted with data analysis and revised the manuscript. All authors read and approved the final version of the manuscript.

Ethical approval

The study protocol was approved by Vishnu Dental College's Institutional Ethical Committee with the reference number (IECVDC/19/PG01/CE/IVT/46).

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